Parallelize Subsurface Flow Simulator using a Hybrid MPI-OpenMP-GPU Approach

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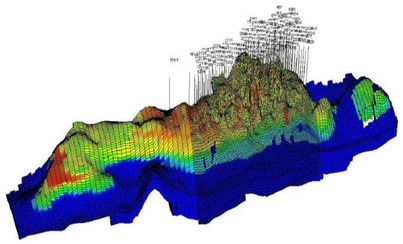
LA-UR-18-26021

Motivation

The Finite Element Heat and Mass Transfer Code (FEHM) has been widely used for a variety of subsurface problems, such as CO2 sequestration, nuclear waste isolation, and oil & gas flow simulation.

However, the computational costs and long time-to-solution become a challenge for large, more realistic reservoir models.

For example, a 3D model with two millions mesh nodes takes around one week to running in serial.

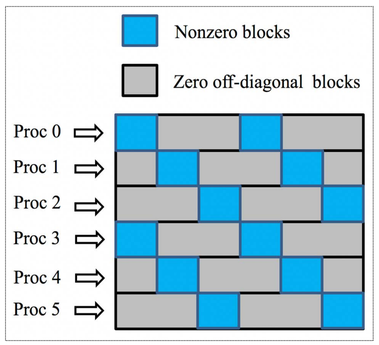


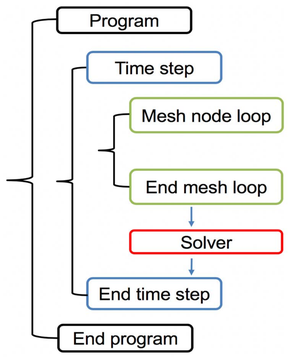
Parallelization Methods

We parallelized and optimized the FEHM through:

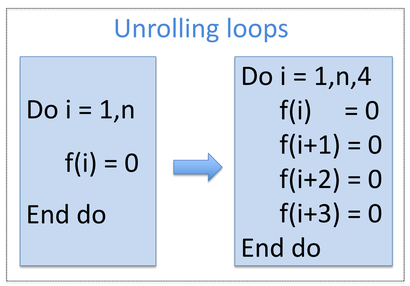
1) Implement MPI-based parallel solver: PETSc
(solver consumes about 60% computational time)

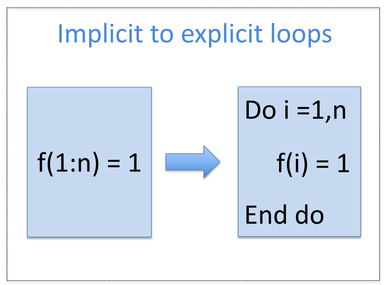
2) MPI-based domain decomposition for scaling capability





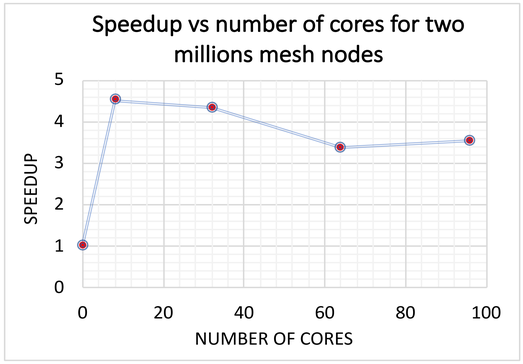
3) Vectorization to efficiently use new computer architecture





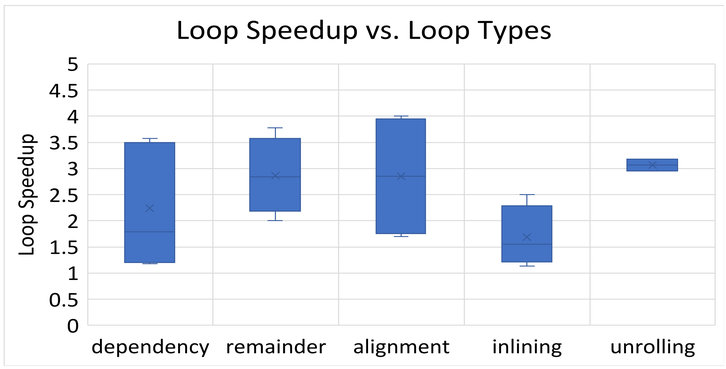
Performance Results

1) PETSc solver (only) performance improvement:



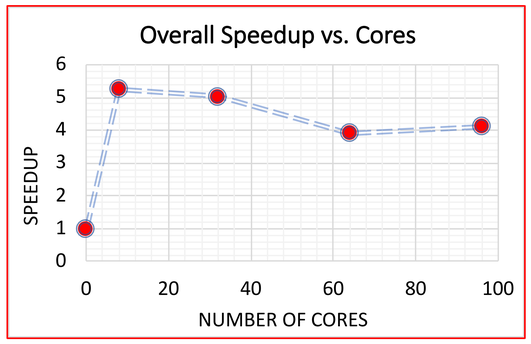
2) Vectorization (only) performance improvement:

Model size (mesh nodes)	36	10,000	100,000	2,000,000
Time Speedup	3.52	3.93	3.33	2.92



Overall Speedup

Five Times Speedup



Contributions

- Speed up the FEHM time-to-solution by 5X
- MPI-based PETSc solver was implemented
- Vectorization was applied to optimize the program
- Domain decomposition is currently in progress
- Future: PETSc for GPUs and threading (OpenMP)

Conclusions

Implementing a library solver can improve scalability and performance, but it comes with many challenges:

✓ Assembling matrix values by block assembly is the most efficient but requires substantial data restructure

Improving existing serial code efficiency through vectorization is essential on modern architectures:

✓ Obtain large efficiency gain with larger vector unit by using profiling tools to identify and optimize “hot spots”

Acknowledgements

Many thanks to the Parallel Computing Summer Research Internship mentors Hai Ah Nam, Bob Robey, Kris Garrett, Eunmo Koo, and Luke Van Roekel.

We would also like to thank the LANL Information Science & Technology Institute for funding this summer project.

This work was performed using Darwin system and supported by the Los Alamos National Laboratory under contract DE-AC52-06NA25396.

References

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